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AIAA-2001-3451

IHPRPT Phase I Solid Boost Demonstrator, A Success Story

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**37th AIAA/ASME/SAE/ASEE
Joint Propulsion Conference and Exhibit
July 8-11, 2001/Salt Lake City, Utah**

IHRPT PHASE I SOLID BOOST DEMONSTRATOR, A SUCCESS STORY

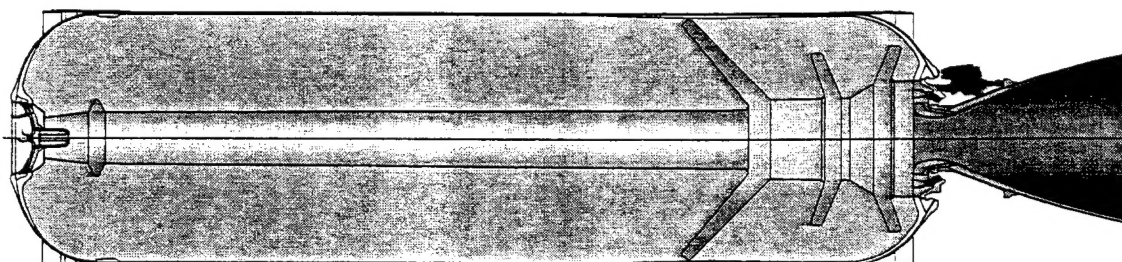
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Abstract

The Integrated High-Payoff Rocket Propulsion Technology or IHRPT program seeks to double the launch capability of the United States by the year 2010. The program is organized into three phases, with a technology demonstrator at the end of each phase. The IHRPT Phase I Solid Boost Demonstrator Program is presented. Materials and

Introduction

The IHRPT Phase I Solid Boost Demonstrator program was a tremendous success at Thiokol. It proved that significant advances are still possible in solid rocket motors where many decision makers in government and industry believe that the embodied technology is fully mature, with no



processing technologies developed under the IHRPT program and on other contracted technology and privately funded programs were combined into one full-scale booster demonstrator culminating six years of new technology work. New materials and processes were used in all components of the demonstration motor to achieve the cost and performance goals identified for the Phase I Boost & Orbit Transfer Propulsion mission area in the IHRPT program. New materials utilized in the motor included low cost high performance carbon fibers in the composite case, energetic ingredients in the propellant, net molded structural parts in the nozzle, and an all-new electromechanical Thrust Vector Actuation (TVA) system. ~~The 92-inch diameter, 300-inch long~~ ^{The} demonstrator in the 120,000 lb class of boosters was successfully static tested on 16 November 2000. The static test has been heralded as a success by government and industry observers alike.

room for improvement. Over a period of 23 months, technologies in all components of the rocket motor were brought together and integrated into a new rocket motor that re-defines the state of the art in solid rocket propulsion.

Two IHRPT programs contributed technology to the demonstration program. The High Performance Case Assembly Technologies (HPCAT) program contracted through the Air Force Research Laboratory (AFRL) developed materials technologies that were integrated into the motor's insulated case. A newly developed prepreg tape was used as dome reinforcements to help reduce case weight, and a new silica filled EPDM internal insulation was developed and demonstrated in the static test. The Class 1.3 Booster Propellant Program, also contracted through AFRL, contributed the bulk of development of the new RDX containing propellant. Both programs had

roots in Thiokol Propulsions IR&D program reaching back several years.

Thiokol Propulsion contributed heavily to the program, not only in technologies developed using discretionary funds, but also contributed approximately half of the funds needed to bring the demonstration test to fruition. All of the effort to build the demonstration motor including all direct labor and materials was supplied by the contract with AFRL. All of the other tasks including engineering design, analysis, drawings, specifications, special tooling and subscale testing was provided by Thiokol discretionary funding. All funds required to setup, instrument and static test the rocket motor were also from Thiokol funds. This work split was a good example of contractor participation and a good example of how government and industry can work together to reach aggressive goals.

IHRPT Program

The IHRPT program began execution in 1996 as a way to focus and direct development of space related technology through government/industry cooperation. The 15 year program is separated into three phases with a demonstration at the end of each phase, the last phase to complete in 2010. Each phase has specific, measurable goals that when attained will push the state of the art past current levels.

Participants in the program are from the Air Force, Navy, Army, OSD, NASA, and from contractors in the space and propulsion industry.

There are three mission application areas included in the program, Boost and Orbit Transfer, Spacecraft, and Tactical. Within each mission application area, there are five technology areas that are addressed: Propellants, Propellant Management Devices, Combustion and Energy Conversion Devices, Controls, and Demonstrators. New materials and processing technology in each of the technology areas are developed in the years leading up to the demonstration of the technology at the end of each phase.

Each participant in the program selects a baseline for their work, and all comparisons and calculations of improvement towards the Phase I goals are made against their baseline. The goals for each of the three phases in the Boost and Orbit Transfer mission area for solid propulsion are shown in Table I.

Table I. Boost and Orbit Transfer Goals for Solid Propulsion.

	Phase I	Phase II	Phase III
Reduce Hardware and Support Cost	15%	25%	35%
Improve Mass Fraction	15%	25%	35%
Improve Specific Impulse	2%	4%	8%
Reduce Stage Failure Rate	25%	50%	75%

Phase I Solid Boost Demonstrator

New technologies in all of the main components of the rocket motor were demonstrated. Propellant, Insulated Case, Nozzle, TVA, and Igniter technology advances combined to assist in meeting Phase I goals.

Propellant

A departure of propellant formulation work performed on the IHRPT Class 1.3 Booster Propellant program, the HTPB propellant formulation incorporated RDX, which increased the energy delivered without increasing hazards as measured using the NOL Large Scale Card Gap test. The resulting formulation was a zero cards, class 1.3 propellant using historical hazards determination tests.

Increasing the energy of the formulation increased motor Isp by over 1%. Mass fraction was increased by 1.9% because the formulation was slightly more dense than the baseline propellant. Cost was impacted somewhat because of the higher cost of RDX compared to typical oxidizers.

Insulated Case

A significant reduction in cost was achieved by implementing one of the new high-strength, low-cost fibers available today. The material is widely used in the composites industry so that material availability and cost will be stable. Combined with Thiokol Corporation Resin (TCR) the prepreg material saved over \$100,000 in materials cost. Figure 1 shows a picture of the insulated case component from the aft end that features the new prepreg material.

While the new prepreg material demonstrated a 10% reduction in strength when compared to the baseline composite, any additional weight required was offset by employing new analytical techniques to design a pressure vessel with a higher stress ratio. Stress ratio compares the stress of fibers in the cylinder to that in the domes. A higher stress ratio translates to fewer layers of material on the pressure vessel and thus less weight.

The use of a higher stress ratio was further improved by using a newly developed carbon fiber prepreg tape that was cut into gore patterns and layed up on the domes to provide local reinforcement of critical high stress areas identified by analysis.

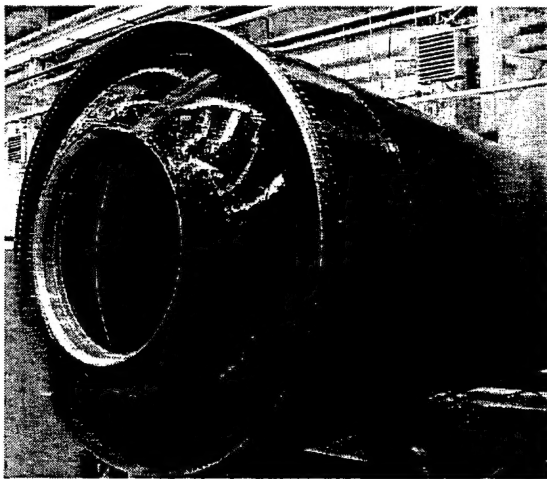


Figure 1. Aft End of Insulated Case Component.

Internal case insulation was also improved for the Boost Demo. The new insulation included silica-filled EPDM that was developed on a predecessor IHRPT program, The High Performance Case Assembly Technologies program. The new insulation demonstrated better ablative performance with slightly less density. The new rubber formulation also addressed an issue of obsolescence where one of the base polymers in the baseline insulation material had gone out of production.

A second new internal insulation was also demonstrated. Developed on the Space Shuttle Asbestos-Free Insulation Replacement Program, this Kevlar filled material provided ablative performance similar to that of the baseline fiber filled insulation, but was more compatible with the new silica filled insulation discussed above.

The combination of new materials used in the insulated case assembly resulted in a cost reduction of 8.2%, and a mass fraction improvement of 7.4% calculated on a motor level.

Nozzle

Developed specifically for the Boost Demonstrator, the new nozzle demonstrated several new materials technologies. The nozzle was an external design that facilitates the expulsion of any slag that might form in the combustion process. Figure 2 shows a picture of the Nozzle in final stages of instrumentation.

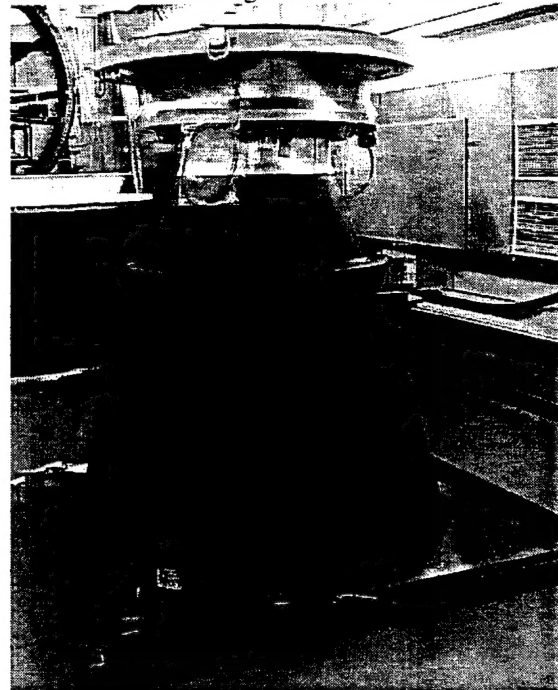


Figure 2. Nozzle prior to assembly to motor.

The new design implemented net molded parts in two critical structural areas, the flexbearing reinforcement shims, and the exit cone adapter. The parts were fabricated from sheet molding compounds made from a chopped fiberglass filled epoxy that is widely used in industry. The clear benefit is the lower labor and materials costs to use net molded parts.

A new Integral Throat Entrance or ITE was also demonstrated. The throat was a carbon-carbon material that demonstrated a gradient density from inside diameter to outside diameter. This approach resulted in higher erosion resistance in the throat where the density was highest, and lower density in the outer diameter where lower weight is preferred for performance improvement. To our

knowledge, this approach has not been demonstrated on this scale before.

Combining all of the nozzle material improvements yielded a motor level cost reduction of 3.8%, a mass fraction improvement of 3.7%, and a Isp improvement of 0.9%.

TVA

The Thrust Vector Actuation or TVA system represented a significant improvement of controls technology. The latest technologies for motors and high power switching were utilized for the demonstration TVA system.

The digital controller was a refinement of technology used for fighter jet control surface actuation, with an analog interface. The digital controller adds a level of flexibility because the microprocessor could be re-programmed to change some performance parameters.

A key improvement was the weight reduction. The new EM system demonstrated a 61% reduction in weight when compared to the baseline hydraulic TVA system.

In total, the TVA improvements resulted in a 5.0% reduction in cost and a 4.9% improvement in mass fraction, calculated on a motor level.

Igniter

New technology was demonstrated in the igniter component also. Net molded closure insulation was implemented to reduce the cost of insulating the igniter closure. This saved significant labor over the prior method of laying up rubber patterns, curing them and then machining to final profile.

A new Safe & Arm (S&A) device was also demonstrated. The new S&A is an electronic device the size of a pill bottle that contains all of the electronics and energy needed to initiate the rocket motor igniter. All electronic functions are powered by the arming input signal. The device is controlled by a microprocessor that performs several safety checks before providing a ready condition signal for ignition. The ¼ lb device is much smaller, lighter and significantly less costly than S&A's flying today.

Stage Failure Rate Reduction

Reducing stage failure rate was also a key part of the IHPRT program. The approach taken for

failure rate reduction was to identify those areas of the motor that have historically shown to cause failures and then improve those areas, thus reducing the probability of failure in that area. The approach of attacking areas of "un-reliability" is warranted, because demonstrating a reduction in stage failure rate in the strict sense of the word is prohibitively expensive in the large solid rocket motor industry.

A baseline failure rate of four failures in a thousand launches was selected as the basis on which to improve. The goal for phase I requires an improvement to three failures in a thousand.

To estimate the stage failure rate of the demonstrated technologies, an analytical approach was taken that examined design safety factors and material variability to calculate an expected failure rate. This approach yielded an estimate for the stage failure rate for the as-built demonstration motor. Estimates as to what could be done in a qualification/production scenario to improve the failure rate were made and a new reliability predicted based on those estimates. The resulting analysis showed that with reasonable maturation of the technologies which were demonstrated in the static test, the goals for phase I stage failure rate could be achieved.

Phase I Goal Achievement

Overall, the approach to calculating goal compliance was to base improvements on measured data were applicable. Since the demonstration motor was a "first-of" production, economies that would be realized during actual fielding of the technology are not demonstrated. Therefore, an attempt was made to project to a post-qualification production scenario the performance and cost to build the motor.

The numbers used to calculate the cost reduction goals were taken from actuals in building the Boost Demonstrator motor, and then anticipated reductions in labor and materials costs for rate production were subtracted from the actuals. The resulting cost savings were totaled and percent improvement calculated. The results for cost improvement can be said to be conservative. Evaluation of cost reductions obtained through continuous improvement on a similar size motor in production showed a 30% reduction within the first 10-12 motors fabricated.

Performance improvements were calculated directly from measurements taken from the static test.

Table II shows the goals and the sum of the motor level contribution from each of the components.

Table II. Achievement of Phase I Goals.

	Goal	Motor	Propellant	Case	Nozzle	Controls
Cost	-15%	-15.2%	1.8%	-8.2%	-3.8%	-5.0%
M_F	15%	17.1%	1.9%	7.4%	3.7%	4.1%
Isp	2%	2.0%	1.1%		0.9%	
Reliability	25%	25.3%	3.1%	4.4%	5.5%	12.3%

Summary

The IHPRPT Phase I Solid Boost Demonstrator successfully demonstrated new technologies that met the goals of the program, and proved that significant improvement can still be made in solid rocket propulsion. The improvements that were demonstrated enable less costly access to space with higher performance. The demonstration test also provides strength to transitioning the technologies to existing and new systems.